Graphs

Memory Diagram

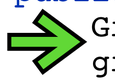
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

Stack				Heap
Name	Value	Name	Value	

- Always start with the main method

in/out

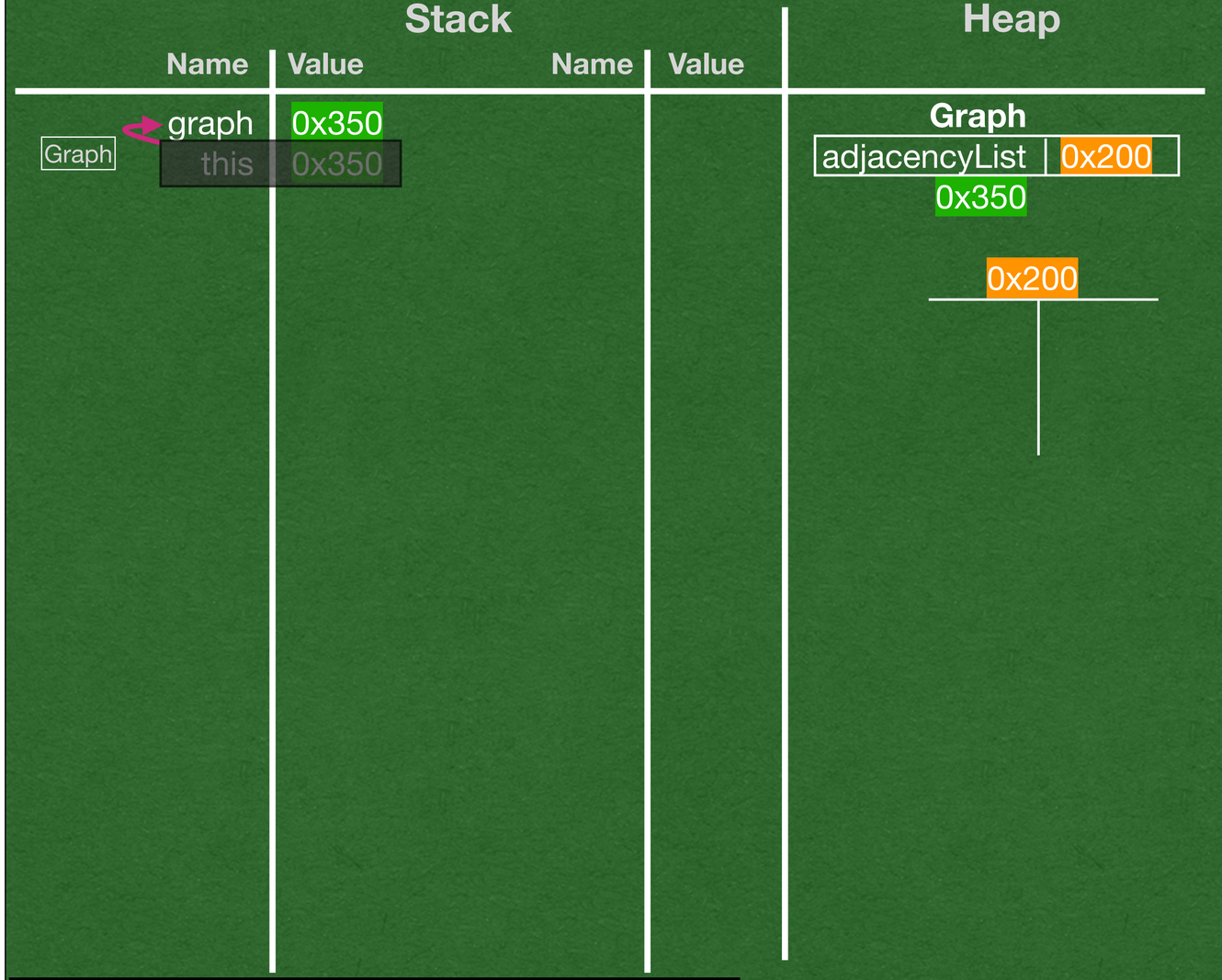
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- The Graph constructor initializes the adjacency list to a new HashMap

in/out

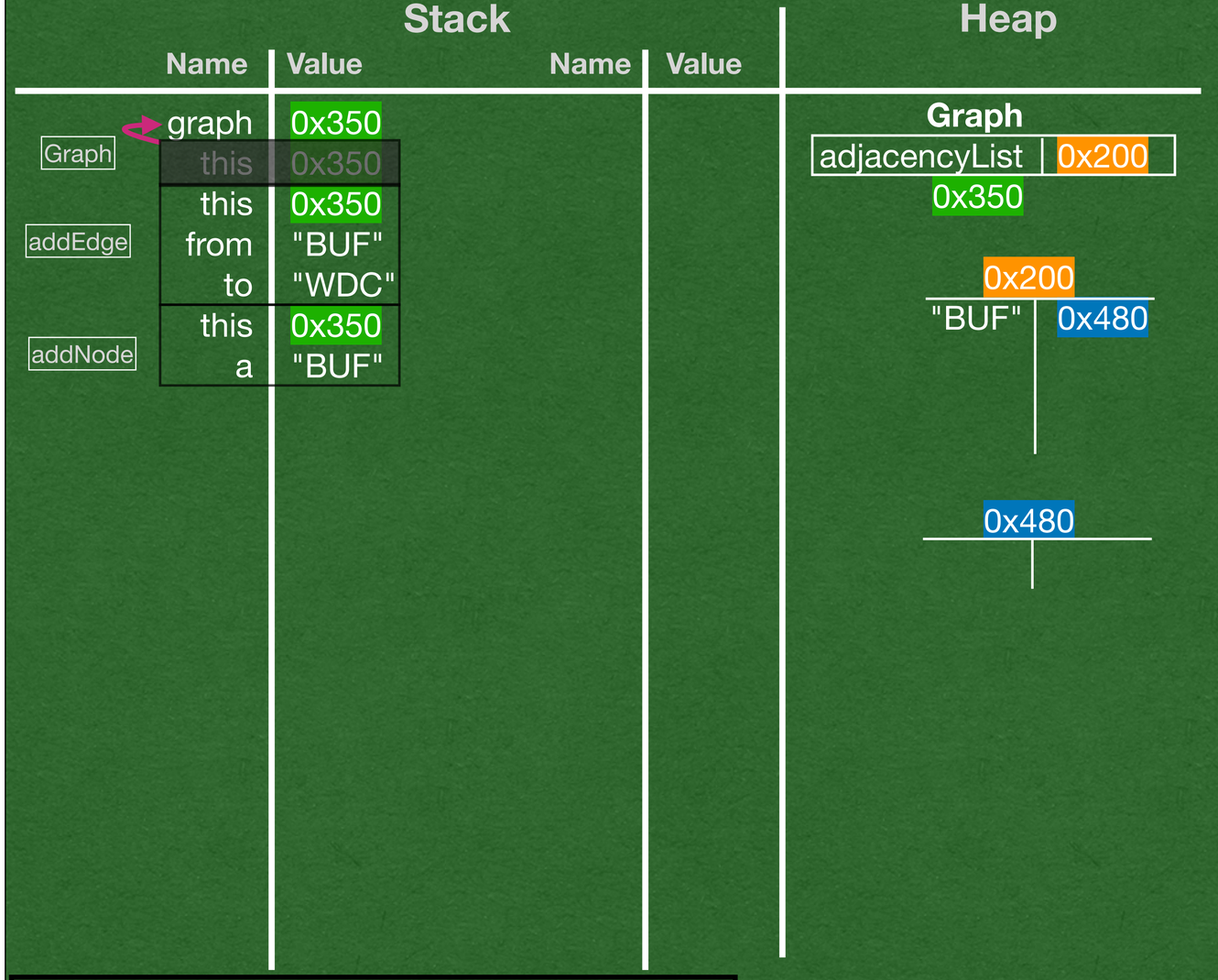
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- We'll add a edge from "BUF" to "WDC"
- Notice this will be a directed graph (Edges only go in one direction)

in/out

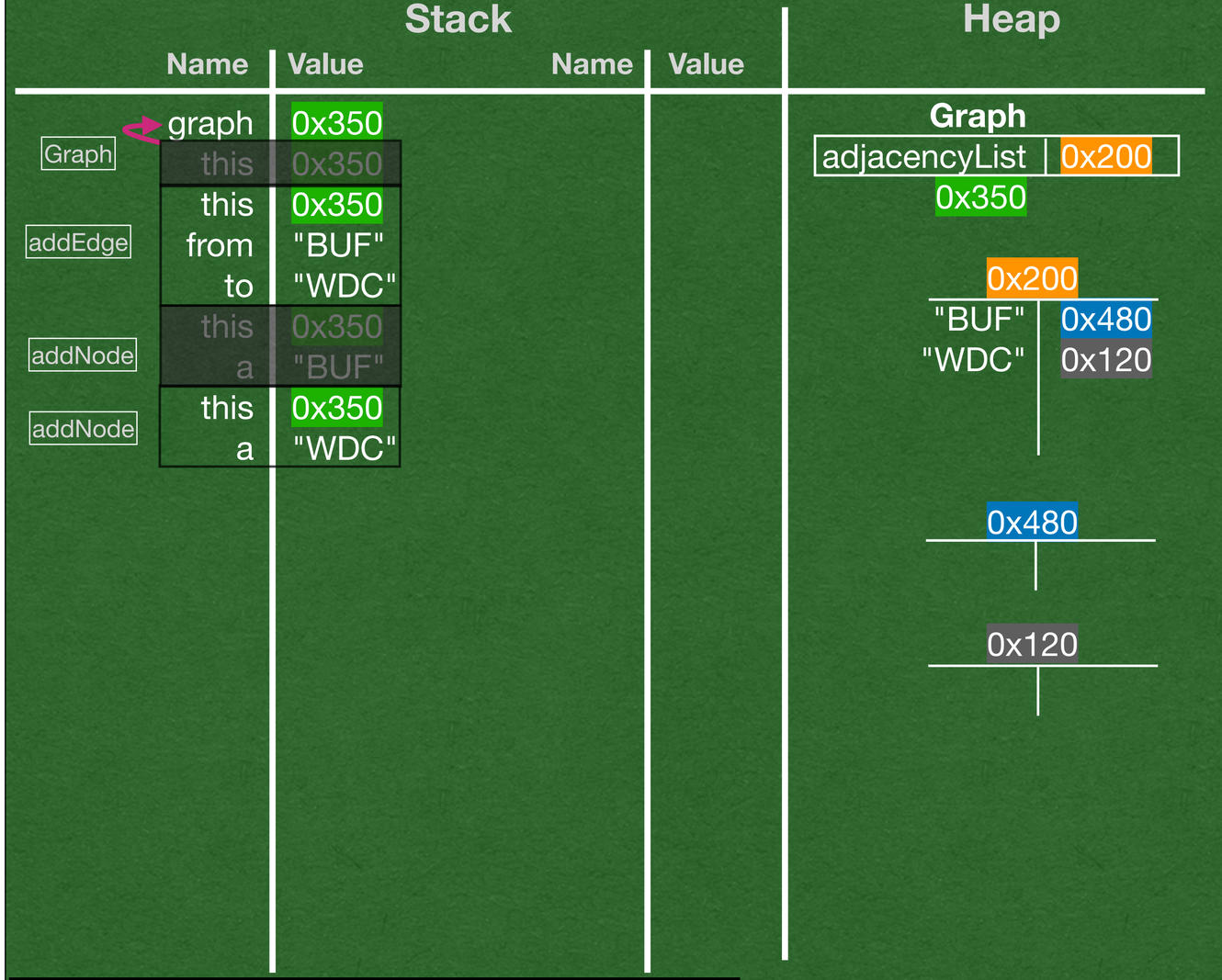
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- We haven't seen the node "BUF" yet
- Initialize it in the adjacency list

in/out

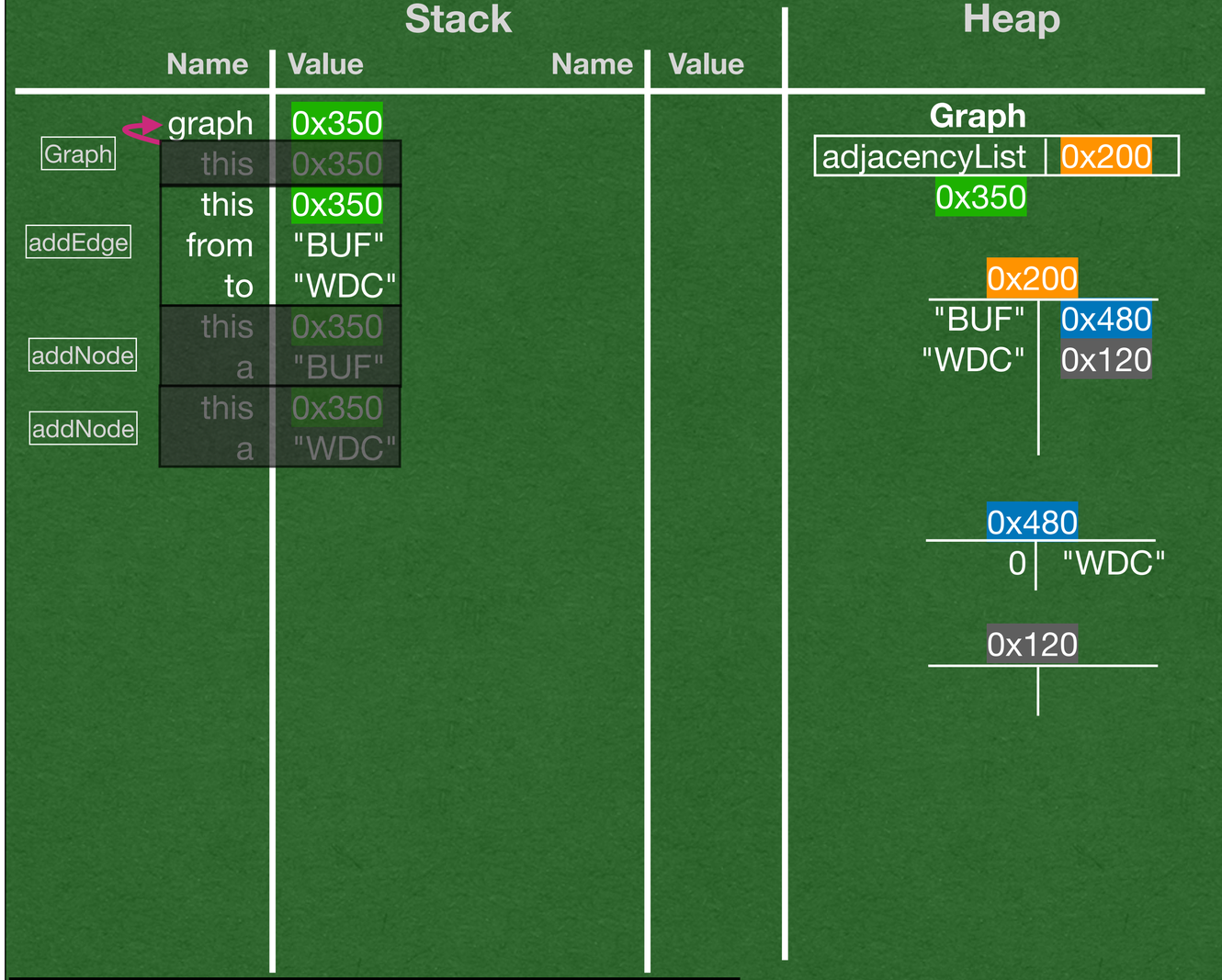
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- We haven't seen the node "WDC" yet
- Initialize it in the adjacency list

in/out

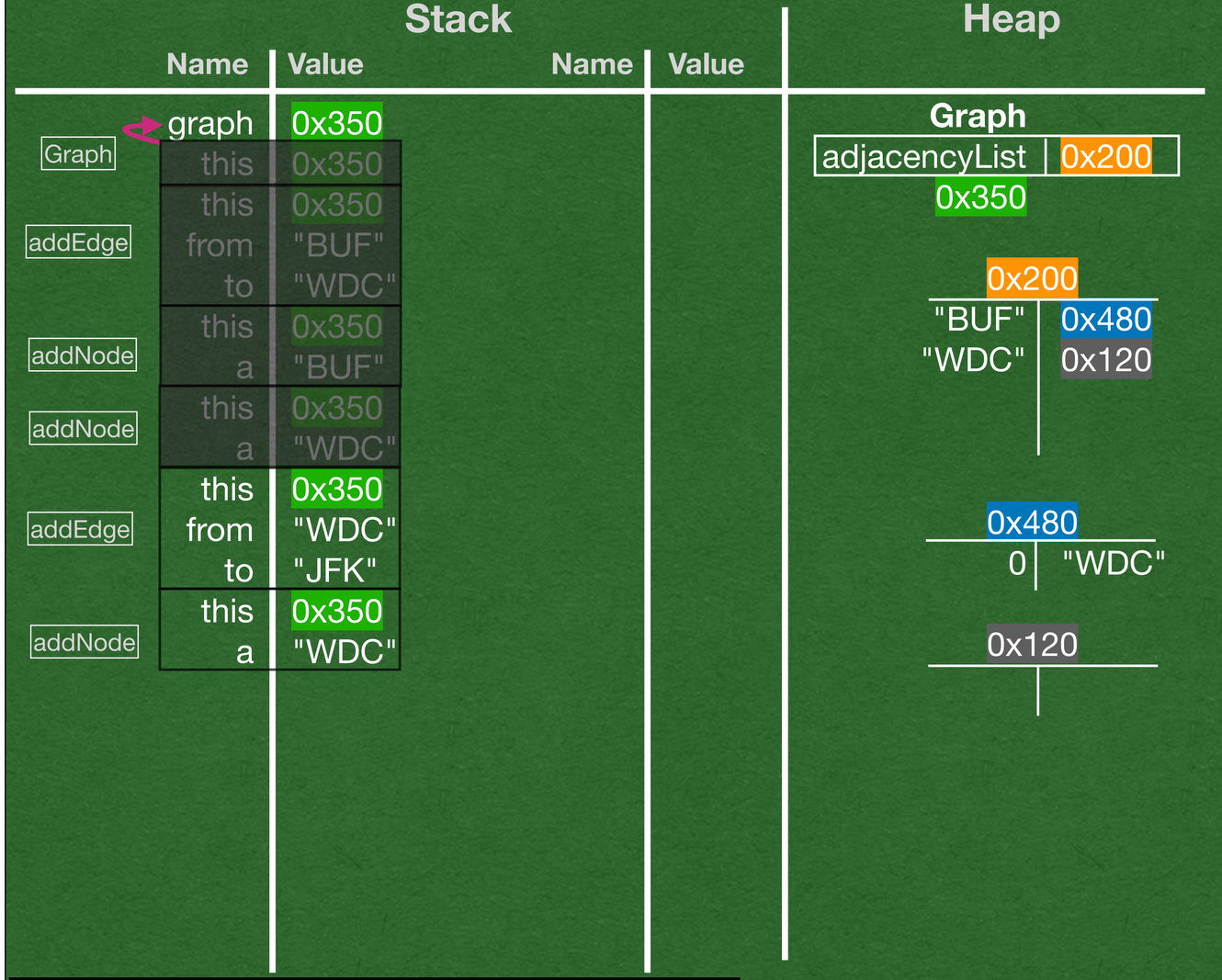
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- Add the edge into the adjacency list

in/out

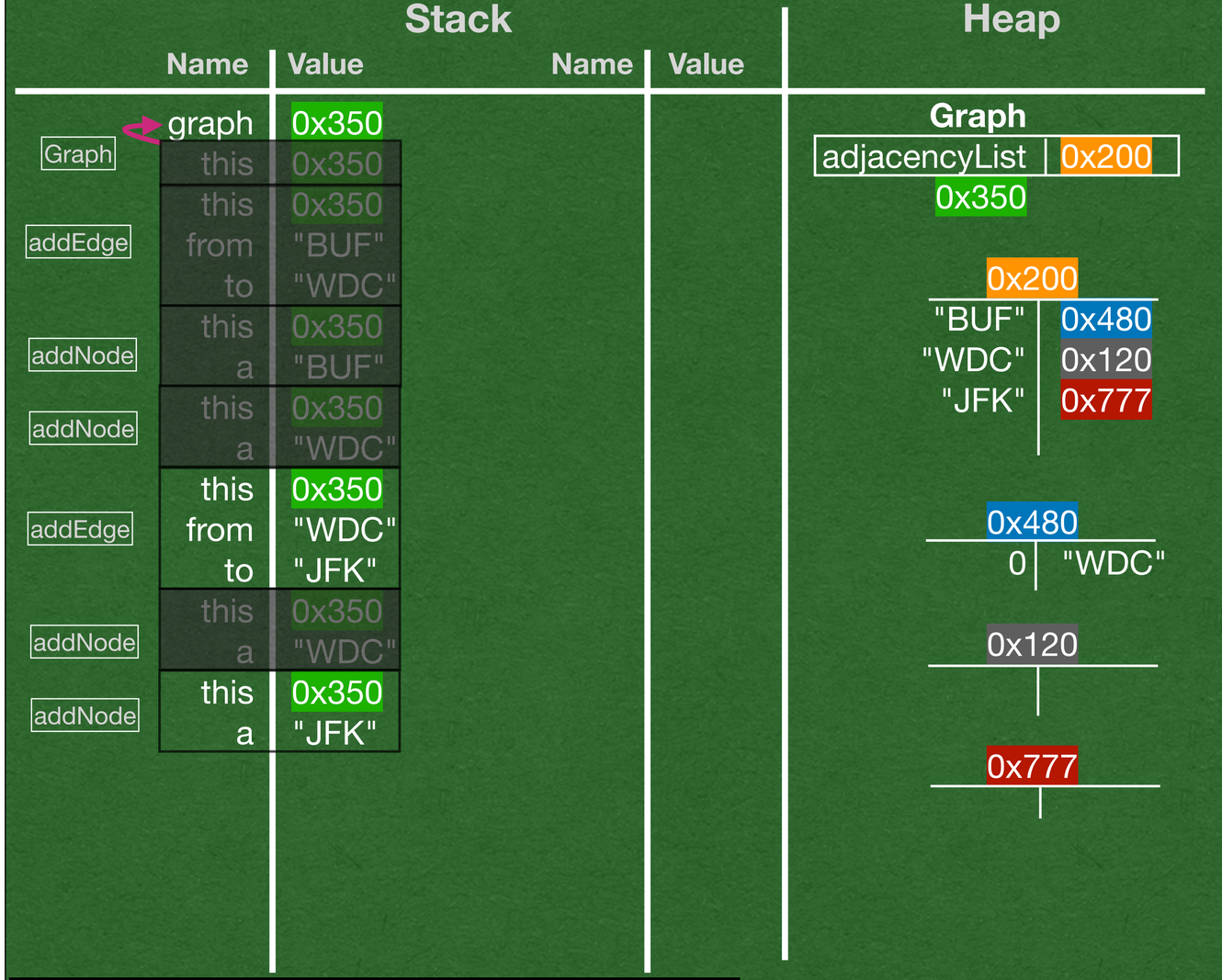
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- "WDC" already has an entry in the adjacency list
- Nothing to initialize

in/out

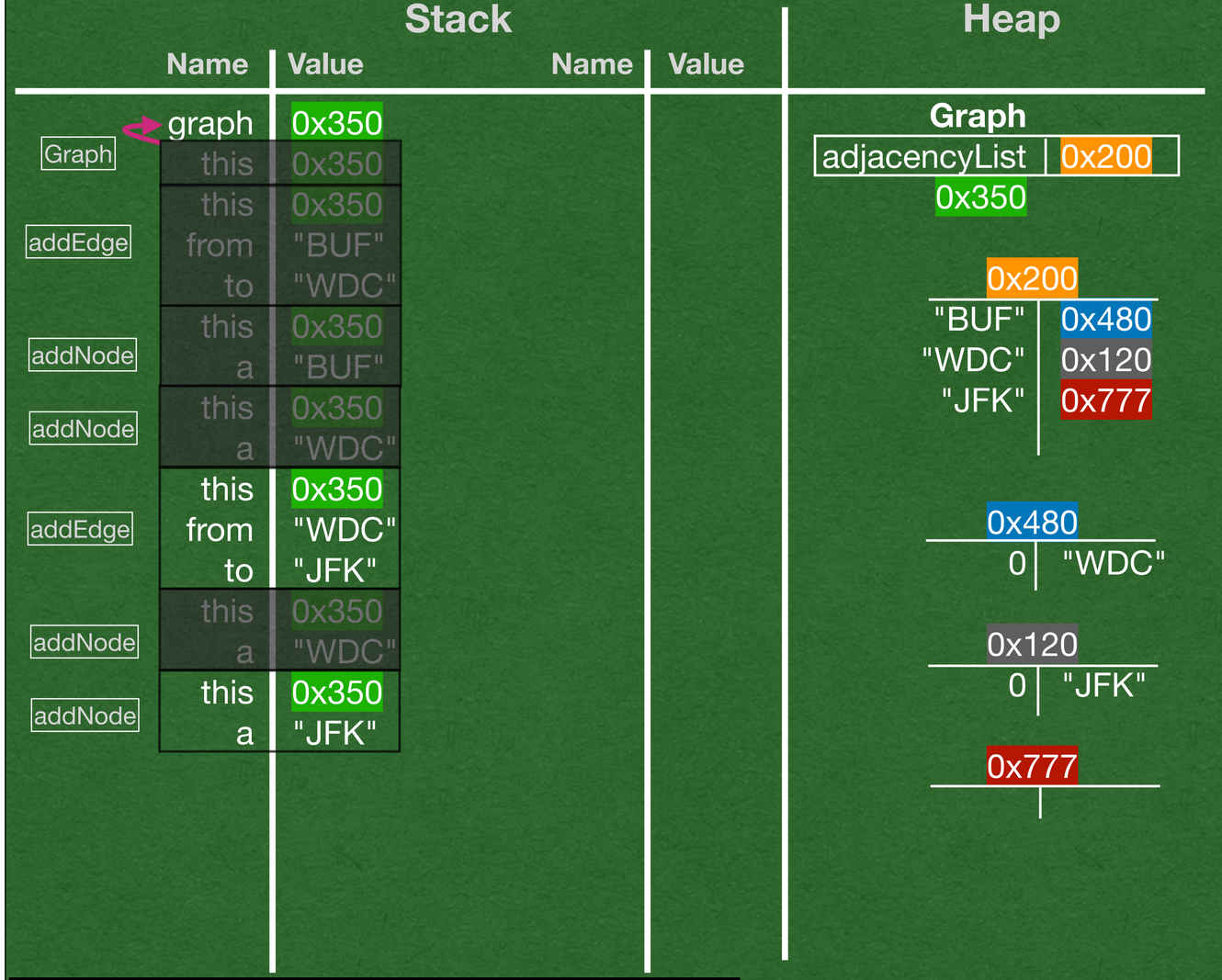
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- Create a new entry in the adjacency list for "JFK"

in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- Add the edge from "WDC" to "JFK" in the adjacency list

in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

- Repeat again for the last edge

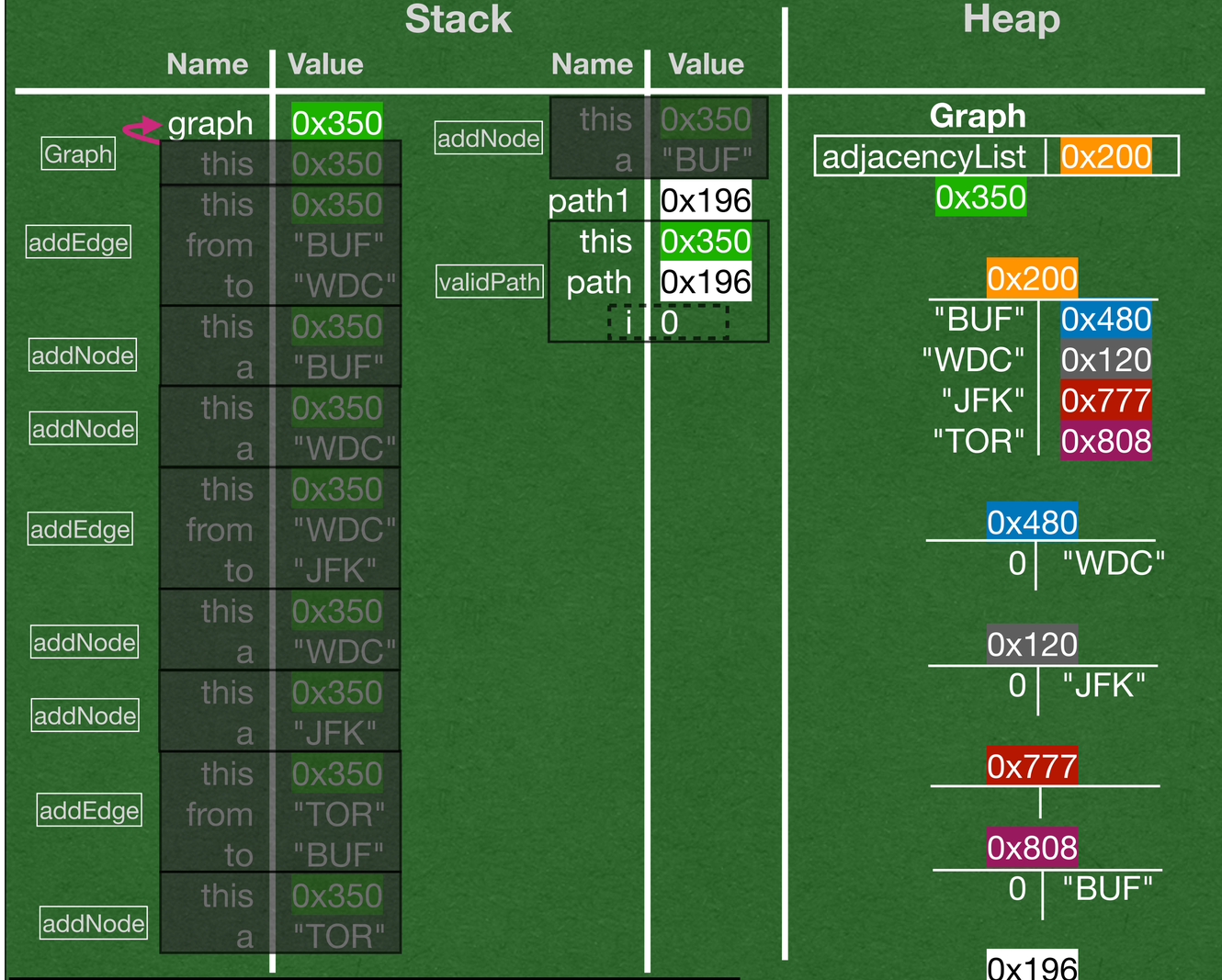
in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

- Create a possible path
- This will be checked by our method

in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- Start the loop that will check if every edge in the path exists in the graph

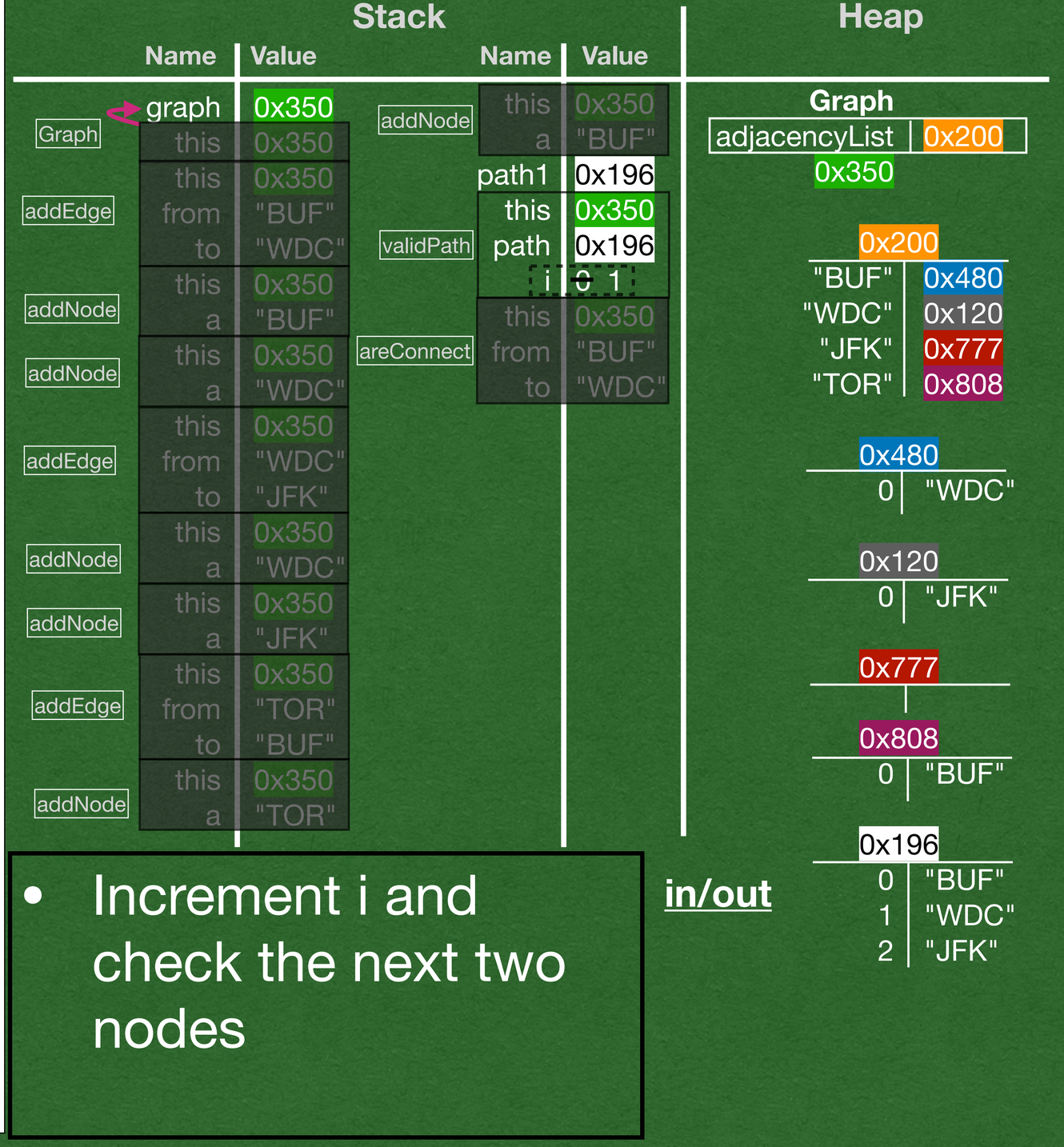
in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

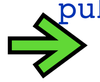
- There is an edge between "BUF" and "WDC", so the method returns true
- Conditional in validPath is false

in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



Stack

Name	Value
Graph	
graph	0x350
this	0x350
addEdge	
this	0x350
from	"BUF"
to	"WDC"
addNode	
this	0x350
a	"BUF"
addNode	
this	0x350
a	"WDC"
addEdge	
this	0x350
from	"WDC"
to	"JFK"
addNode	
this	0x350
a	"WDC"
addNode	
this	0x350
a	"JFK"
addEdge	
this	0x350
from	"TOR"
to	"BUF"
addNode	
this	0x350
a	"TOR"

Name	Value
addNode	
this	0x350
a	"BUF"
path1	0x196
validPath	
this	0x350
path	0x196
i	~~0~~ 1
areConnect	
this	0x350
from	"BUF"
to	"WDC"
areConnect	
this	0x350
from	"WDC"
to	"JFK"

Heap

Graph

adjacencyList	0x200

0x350

0x200

"BUF"	0x480
"WDC"	0x120
"JFK"	0x777
"TOR"	0x808

0x480

0	"WDC"

0x120

0	"JFK"

0x777

0x808

0	"BUF"

0x196

0	"BUF"
1	"WDC"
2	"JFK"

- There is an edge between "WDC" and "JFK", so the method returns true
- Conditional in validPath is false

in/out

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

Stack

Name	Value
Graph: graph	0x350
Graph: this	0x350
addEdge: this	0x350
addEdge: from	"BUF"
addEdge: to	"WDC"
addNode: this	0x350
addNode: a	"BUF"
addNode: this	0x350
addNode: a	"WDC"
addEdge: this	0x350
addEdge: from	"WDC"
addEdge: to	"JFK"
addNode: this	0x350
addNode: a	"WDC"
addNode: this	0x350
addNode: a	"JFK"
addEdge: this	0x350
addEdge: from	"TOR"
addEdge: to	"BUF"
addNode: this	0x350
addNode: a	"TOR"

Name	Value
addNode: this	0x350
addNode: a	"BUF"
path1	0x196
validPath: this	0x350
validPath: path	0x196
validPath: i = 0	1
areConnect: this	0x350
areConnect: from	"BUF"
areConnect: to	"WDC"
areConnect: this	0x350
areConnect: from	"WDC"
areConnect: to	"JFK"

Heap

Graph

adjacencyList	0x200

0x350

0x200

"BUF"	0x480
"WDC"	0x120
"JFK"	0x777
"TOR"	0x808

0x480

0	"WDC"

0x120

0	"JFK"

0x777

0x808

0	"BUF"

0x196

0	"BUF"
1	"WDC"
2	"JFK"

- The loop condition is false
- We made it through the loop without returning false, therefor all the edges exist and we can return true

in/out

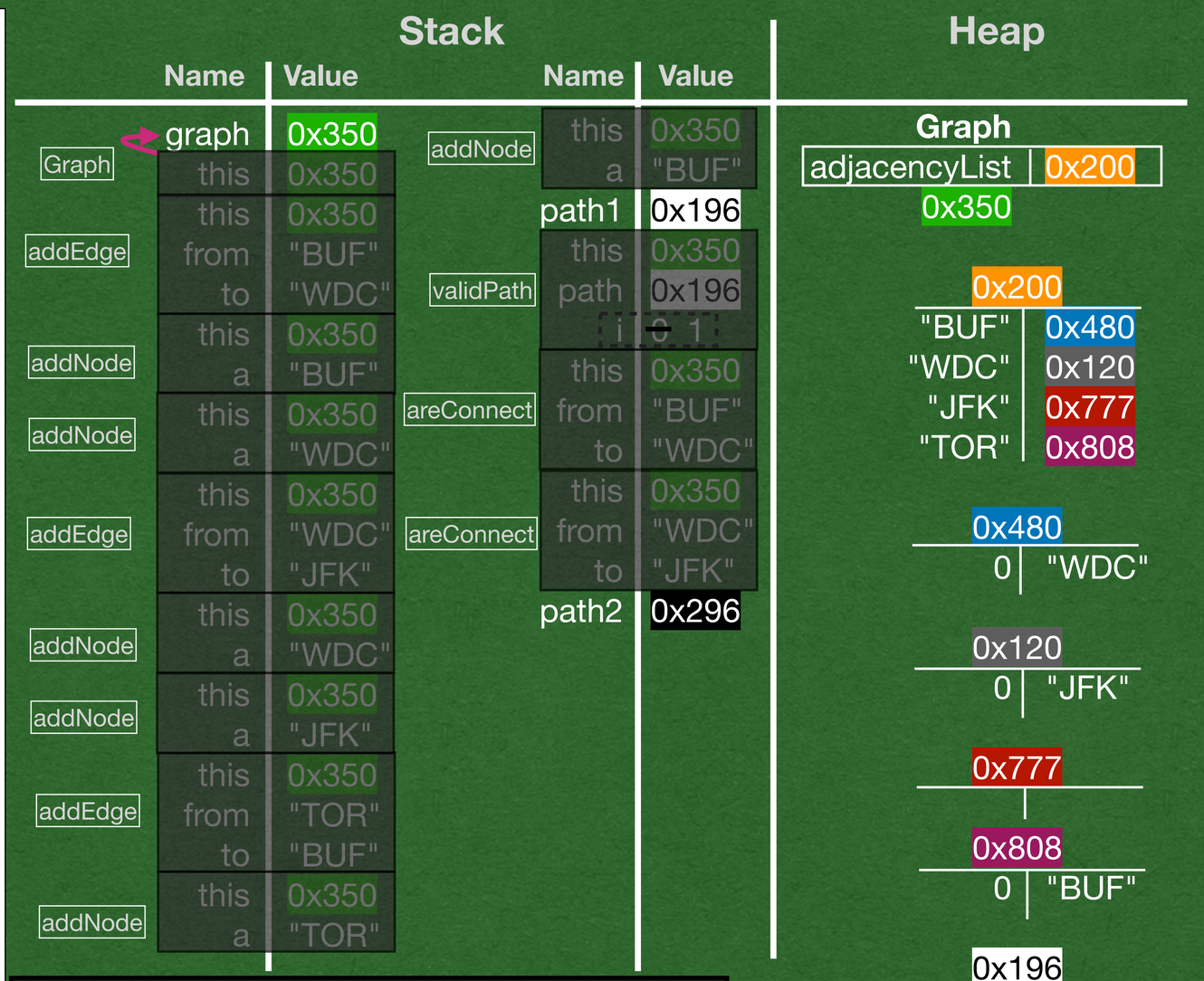
```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

- Print true to the screen

in/out

```
true
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

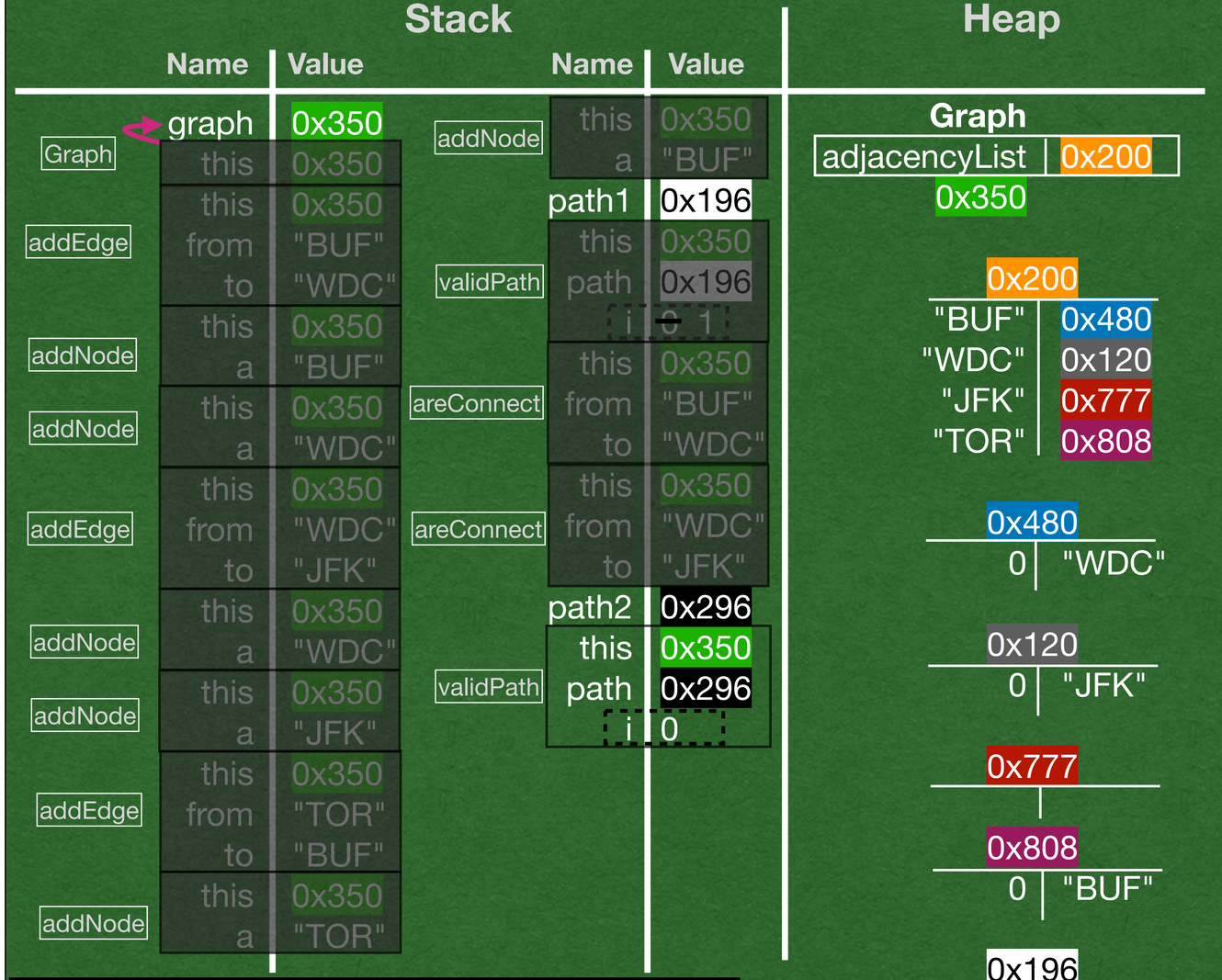


- Create a new ArrayList with another possible path to check

in/out

```
true
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

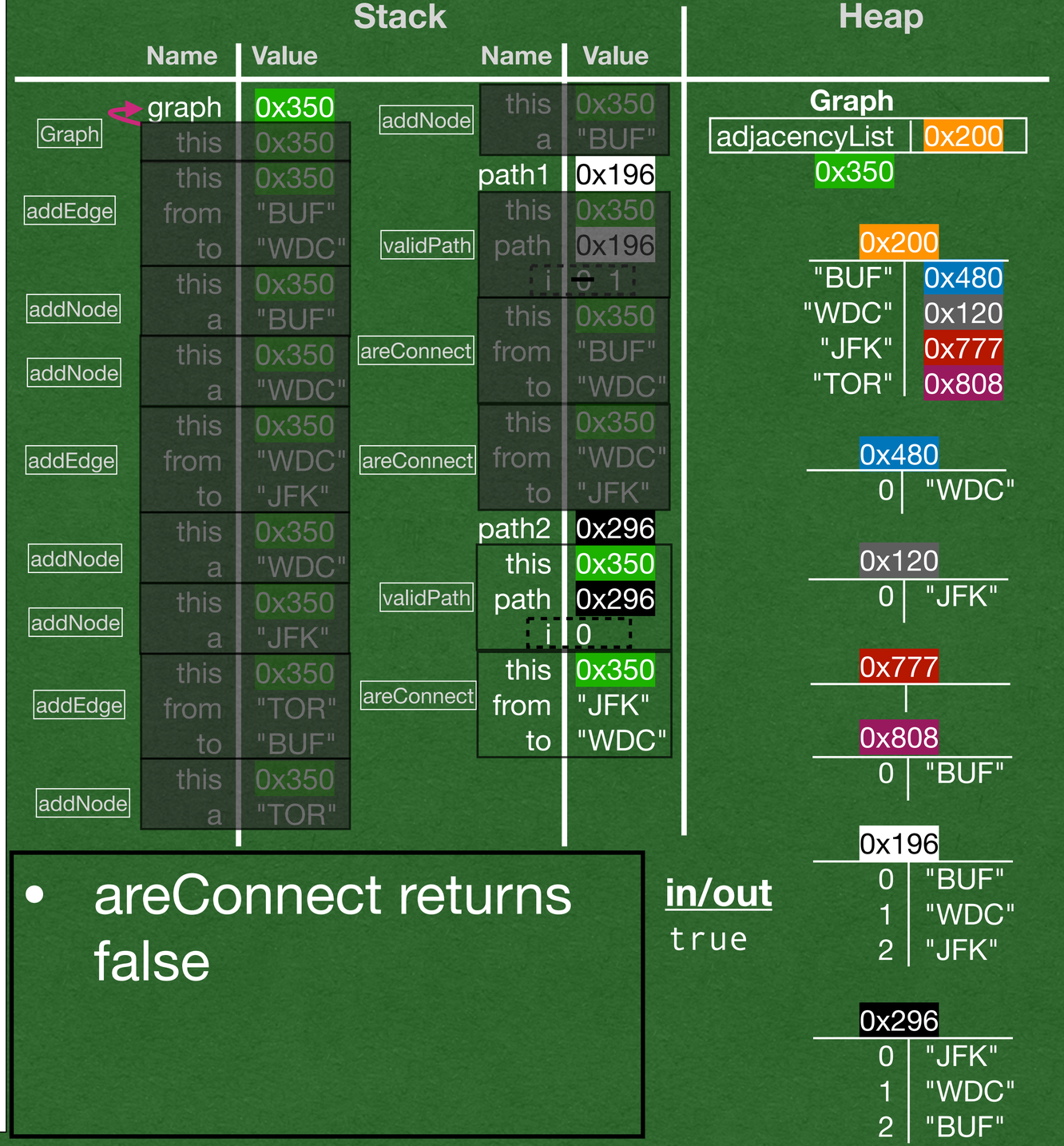


- Valid path with check if the values at indices 0 and 1 are connected

in/out

```
true
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
                this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

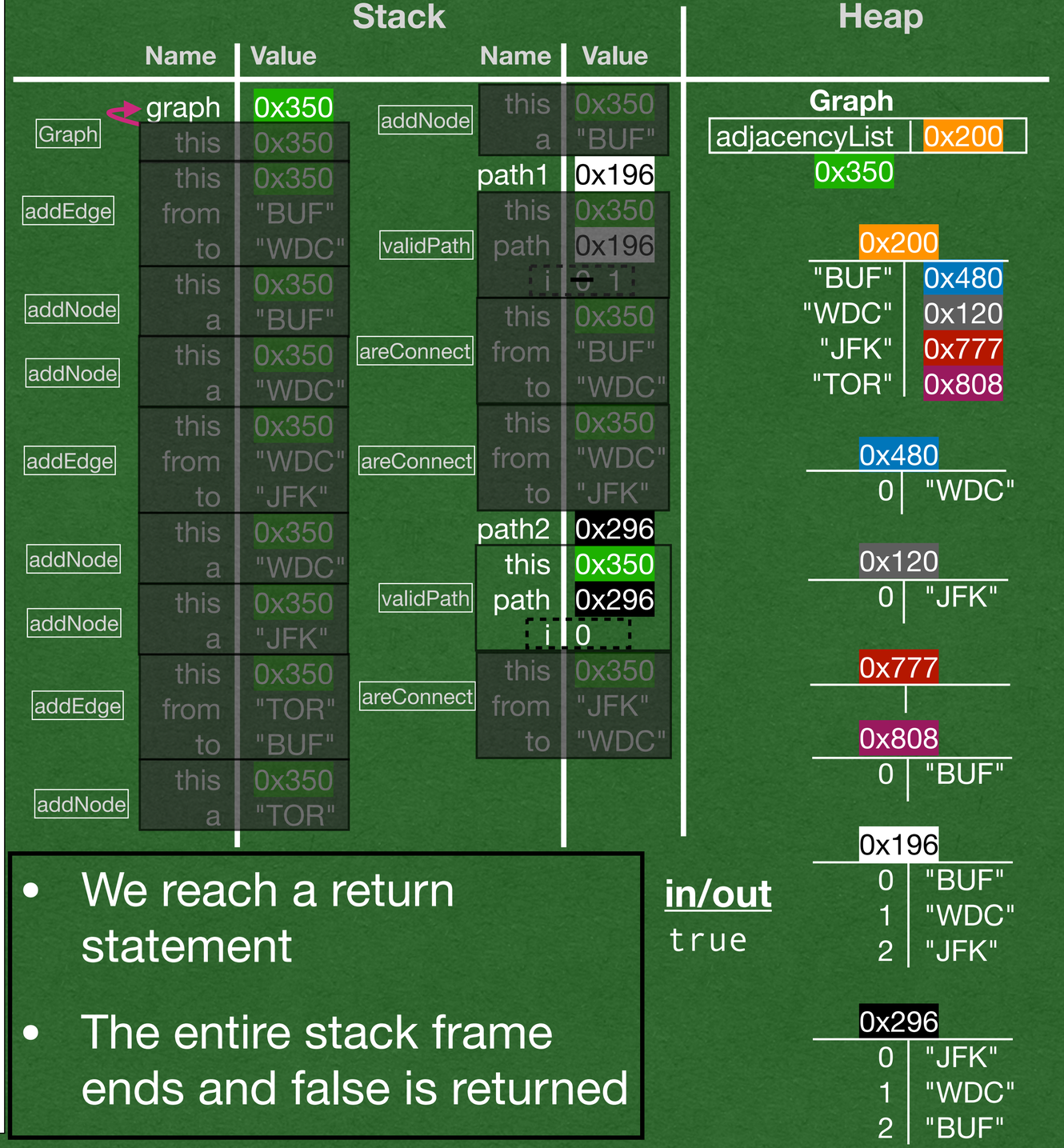


- areConnect returns false

in/out

```
true
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

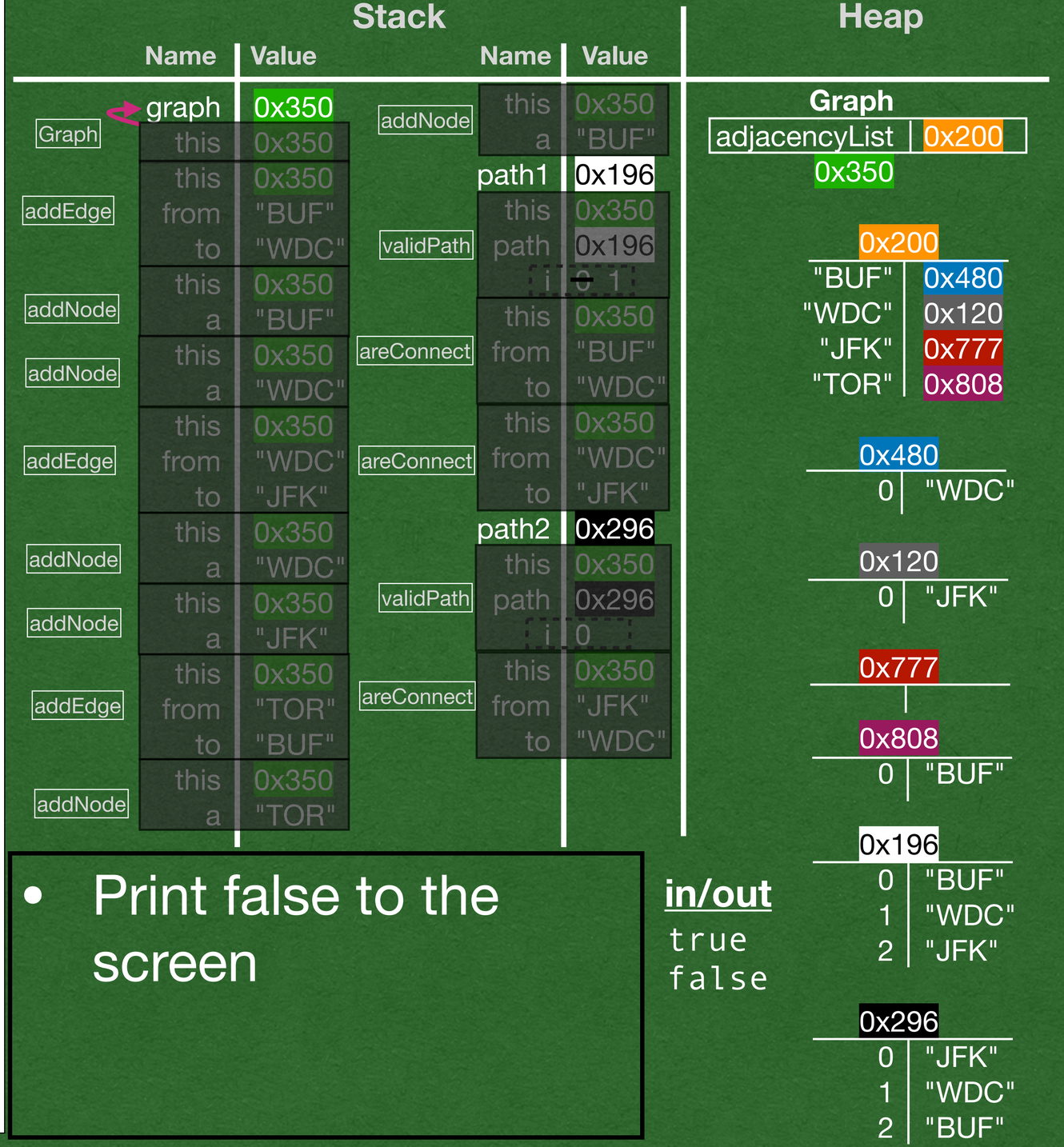


- We reach a return statement
- The entire stack frame ends and false is returned

in/out

```
true
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
               this.adjacencyList.get(from).contains(to);
    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```



- Print false to the screen

in/out

```
true
false
```

```java
public class Graph<N> {
    private HashMap<N, ArrayList<N>> adjacencyList;
    public Graph() {
        this.adjacencyList = new HashMap<>();
    }
    public void addEdge(N from, N to) {
        this.addNode(from);
        this.addNode(to);
        this.adjacencyList.get(from).add(to);
    }
    private void addNode(N a) {
        if (!this.adjacencyList.containsKey(a)) {
            this.adjacencyList.put(a, new ArrayList<>());
        }
    }
    public boolean areConnect(N from, N to){
        return this.adjacencyList.containsKey(from) &&
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    }
    public boolean validPath(ArrayList<N> path) {
        for (int i=0; i < path.size()-1; i++) {
            if(!this.areConnected(path.get(i), path.get(i+1))){
                return false;
            }
        }
        return true;
    }
    public static void main(String[] args) {
        Graph<String> graph = new Graph<>();
        graph.addEdge("BUF", "WDC");
        graph.addEdge("WDC", "JFK");
        graph.addEdge("TOR", "BUF");
        ArrayList<String> path1 = new ArrayList<>(
                Arrays.asList("BUF", "WDC", "JFK"));
        System.out.println(graph.validPath(path1));
        ArrayList<String> path2 = new ArrayList<>(
                Arrays.asList( "JFK", "WDC", "BUF"));
        System.out.println(graph.validPath(path2));
    }
}
```

- Program ends
- Last lecture memory diagram ends

in/out

```
true
false
```